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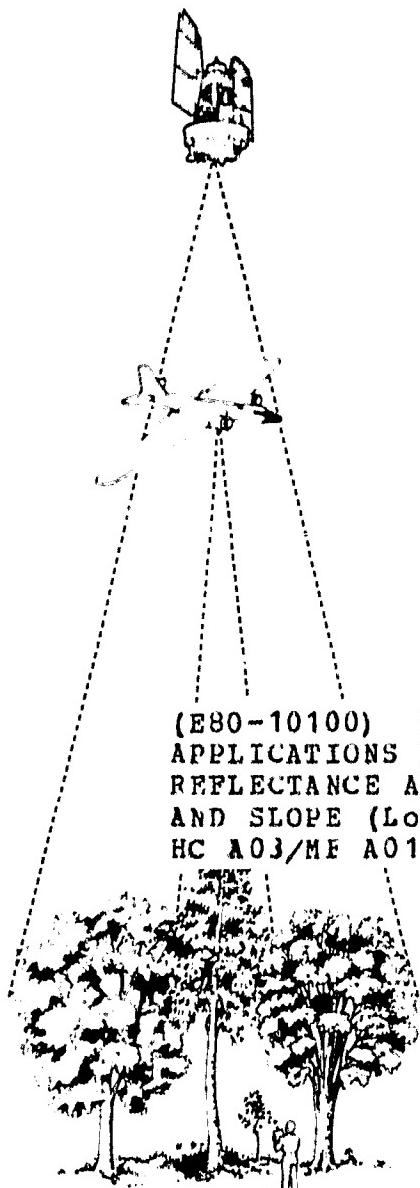
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NATIONWIDE FORESTRY APPLICATIONS PROGRAM



CORRECTIONS TO FOREST REFLECTANCE AS
A FUNCTION OF LOW SUN ANGLE AND SLOPE

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FOREST SERVICE
U.S. Department of Agriculture

PREFACE

This document reports the preliminary processing and analysis efforts on one phase of a project designed to improve the classification of forest inventories. The work focused on the differentiation of forest type signatures in hilly and mountainous terrain where the effects of low Sun angle induced a wide variation in like signature response.

The authors wish to acknowledge the assistance of Dr. B. F. Edwards of Lockheed Electronics Company, Inc. for his editorial comments and recommendations pertaining to the illumination model.

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1. INTRODUCTION

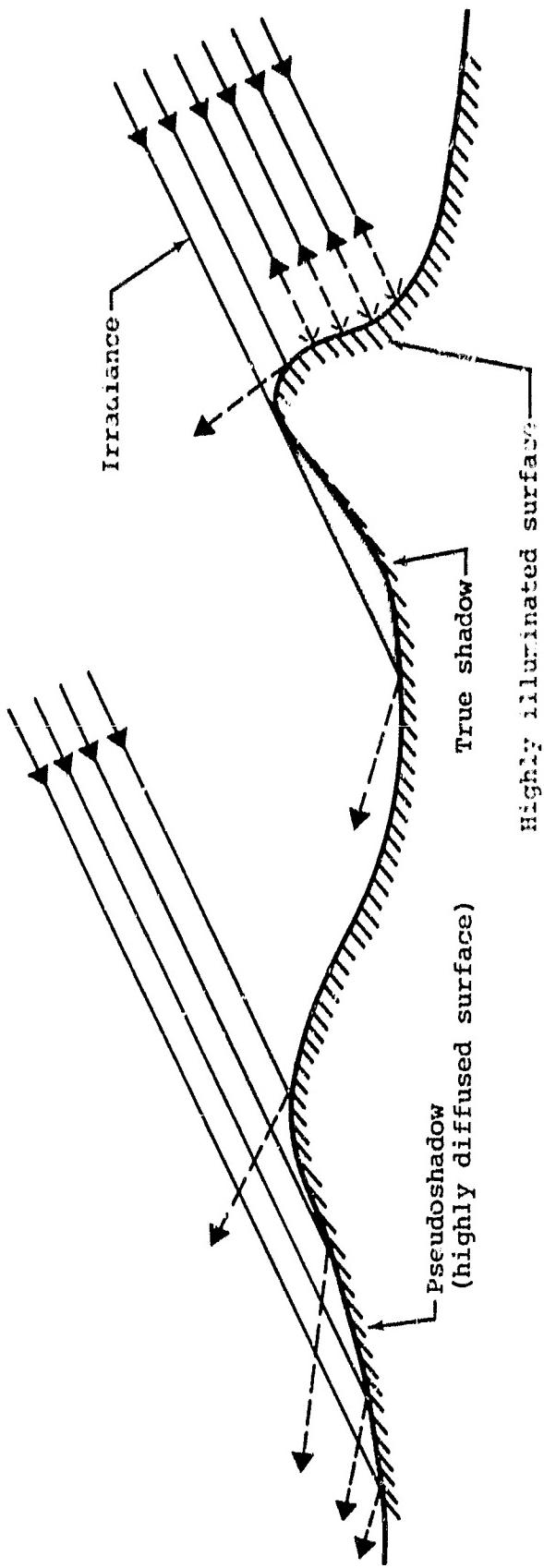
This paper describes the procedures and results of a very brief study of the relationship between forest reflectance, terrain slope and a low Sun angle and its effect on Landsat spectral data. To expedite the study, simplified techniques and approximations were employed and which are described fully in appendix B. The study was stimulated by previous work conducted during the Ten-Ecosystem Study (TES) for Washington County, Missouri. During the photographic analysis phase of this project, it was observed that both the high altitude photography and Landsat imagery displayed an unusual amount of shadow caused by the hilly terrain. This effect was accentuated by the intensity of the Sun's irradiance on the slope facing the southeast (direction of the Sun's rays) and the opposite slope where the irradiance just grazed the surface. The relative brightness of the two surfaces gave rise to the initial assumption of shadows being projected by the terrain. This phenomenon was especially noticeable in the northwestern portion of the county where the terrain was well dissected by numerous headward working streams giving a topographic expression in the form of narrow ridges and poorly defined valleys. A later analysis of the topographic data showed that the average slope was not steep enough to cast a *true shadow and that the observed phenomenon was caused by a combination of slope, Sun elevation, and bidirectional reflectance of the surface features (fig. 1).

2. OBJECTIVES

The objectives of this study are two-fold:

- a. To determine the effects of the low Sun angle and slope on spectral/environmental signatures obtained from Landsat imagery

*A shadow cast by an opaque body as compared to an apparent shadow (pseudoshadow) which may be attributed to the bidirectional characteristics of the surface or angle of illumination.



NOTE: Relative degree of diffused incident light provides contrast in transmitted light, resulting in a pseudoshadow effect.

NOTE: True shadow effect produced on back slope.

(a) Terrain slope less than Sun angle. (b) Terrain slope greater than Sun angle.

Figure 1.— Pseudoshadow effects in hilly terrain.

- b. To find a means of reducing the effects of this phenomenon so as to increase the accuracy of future computer classifications

3. STUDY AREA

The study area is centered in the northwestern quadrant of Washington County, Missouri (fig. 2). The topography of the area can best be described as consisting of moderately steep ridges with a mean gradient of approximately 20 degrees and a maximum gradient of 30 degrees. The axial trend of the slopes is northwest/southeast; however, this is subject to local variations. The relief is approximately 77.2 meters (250 feet) while the highest elevation in the area is Flint Hill, with an elevation of 402.3 meters (1320 feet) above mean sea level.

The vegetation consists of mixed hardwoods principally oak and oak-hickory, with minor stands of pine and cedar. The pine and cedar plantations occur in isolated stands and are usually confined to the upper slopes. Due to the hilly terrain and thick forest canopy, grasslands are invariably located in the narrow valleys and, for the most part, consist of well developed pastures. In this quadrant of the county, approximately 85 percent of the area is hardwood, 10 percent grassland, and 5 percent softwood.

4. MATERIAL AND EQUIPMENT

The General Electric Image 100 Interactive Computer was utilized extensively for the image display capabilities of the system, signature acquisition, and classification. Landsat data from scene 1845-1559 dated November 15, 1974¹, was utilized during the

¹This Landsat scene was utilized during the TES when the phenomenon was first observed.

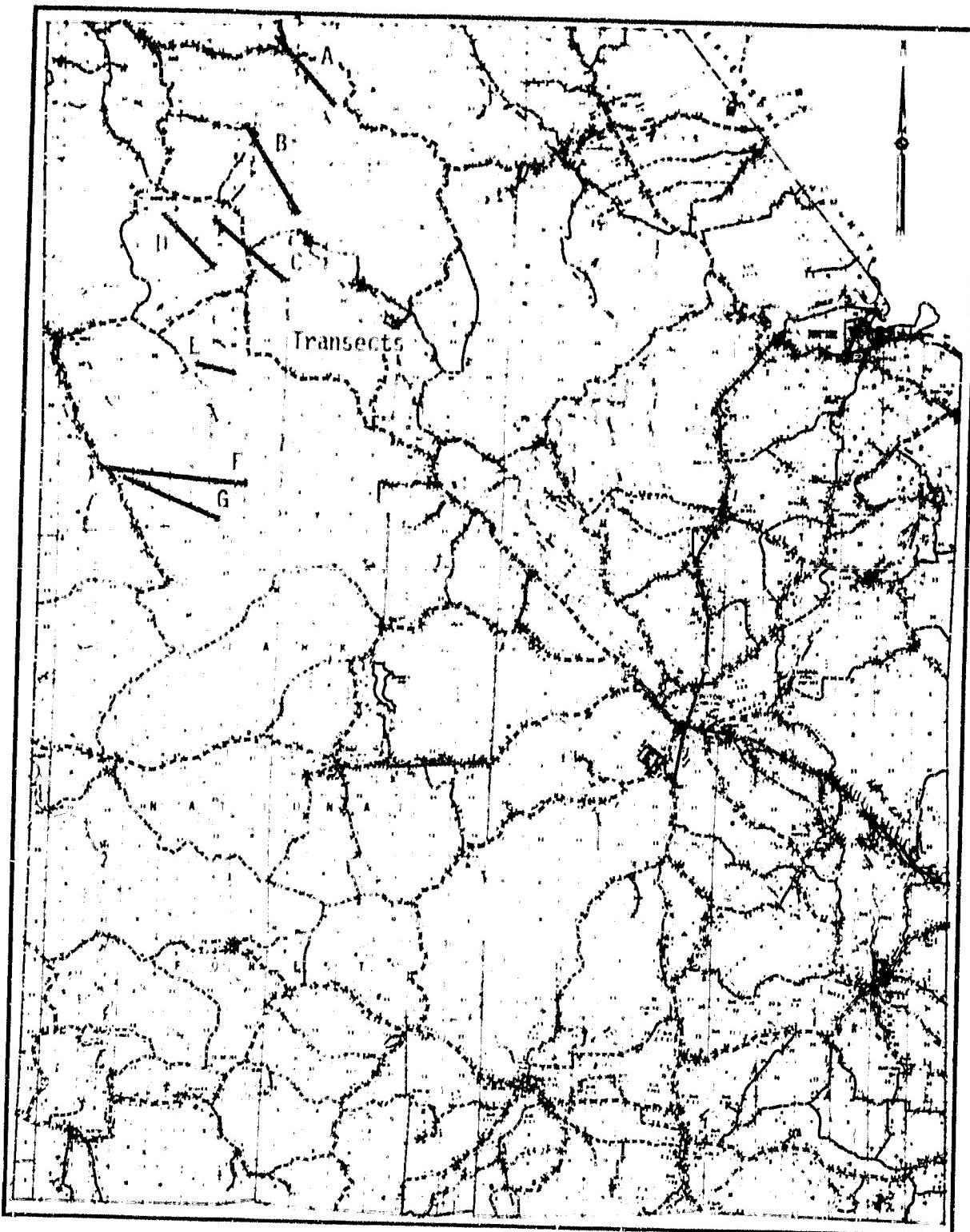


Figure 2.- Selected study sites in Washington County, Missouri
(scale approximately 1:256,500).

study as it displayed a reflectance characteristic of a low Sun angle (28 degrees). High altitude color infrared (CIR) photography from Mission 289, flown September 1974, was utilized as an aid in selecting the seven transects, identification of vegetation, and for the correlation of the topography with contour data from the U. S. Geological Survey (USGS) Richwoods quadrangle at 1:62,500 scale. In order to verify the vegetation cover obscured by the pseudoshadows, the following imagery taken during a period of higher Sun angle were utilized: Landsat scene 1737+6025, July 30, 1974, and high altitude CIR photography from Mission 289, flown September 1974.

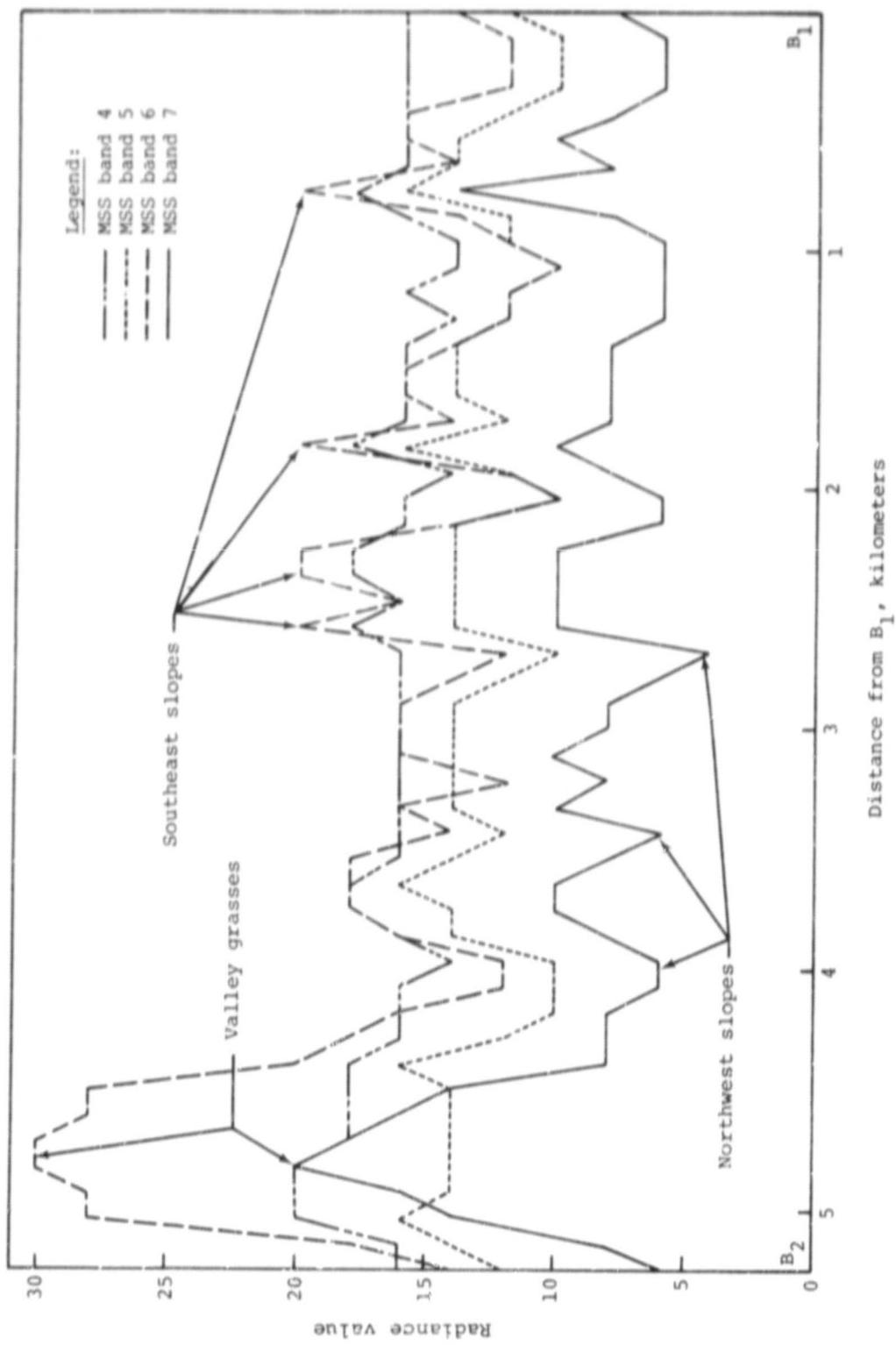
2. APPROACH

The approach was straightforward - spectral measurements of the Landsat imagery were obtained of selected areas which displayed well defined apparent shadowing effects, and similar, if not identical, vegetation cover and aspect angle. Correction factors were then obtained for each slope and applied to the initial measurements, thus correcting all data to a Sun angle normal to the surface. It was hypothesized that the application of these corrections to the hardwood signatures would reduce the variation in spectral response of the signatures obtained from the slopes for all angles. Assuming this could be achieved, with only minor residuals, then means could be developed whereby these corrected values could be applied to the Landsat data with the intent of improving the data prior to classification. It should be noted that the effects of atmospheric factors, change of aspect, Sun azimuth, sensor look angle (and a host of others) have not been considered as part of this report since the main theme is directed towards maintaining a simplistic approach.

6. PRELIMINARY TECHNIQUE

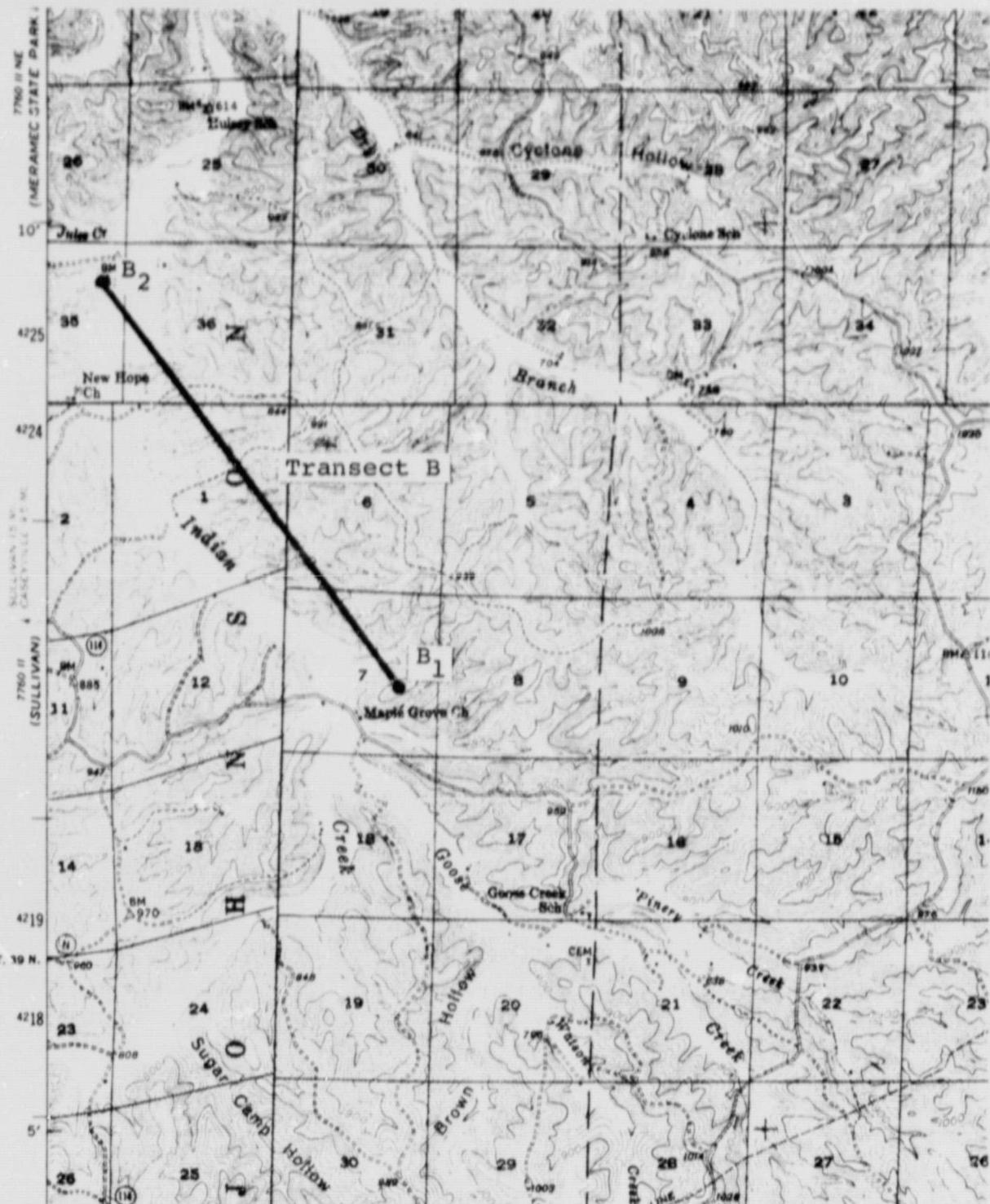
For the purpose of assessing the effects of the apparent shadows or "pseudoshadows" as shown in figure 1, seven potential study sites in the form of transects were selected from the Landsat imagery. Each transect was characterized by certain features which might influence the spectral response, i.e., azimuthal orientation of the transect, vegetation cover types, slope and aspect, and the pseudoshadow effects. Care was exercised to insure that the vegetation cover along the transect was uniform and that each transect was oriented normal to the mean axial trend of the ridges so that the Landsat radiometric measurements could be recorded along the direction of maximum slope. Prior to mensuration of the radience values, the transects were transferred to the aerial photography so that the terrain slopes could be accurately identified and correlated with the radience values. Once the slopes were identified, the aspect angle was then determined by transposing the trace of the transect to the USGS map source and computing the degree of slope from the contour information and base distance of the slope.

To implement the study, a spectral response profile (fig. 3) was made across Transect B (fig. 4) to provide preliminary data to determine how the spectral response varied with the topography and vegetation cover. The spectral measurements were obtained from the Landsat imagery utilizing the Image 100 system. The resolution (number of gray levels) was set at 128 for bands 4, 5, and 6 while band 7 was set at 64 so that the trace of the profile would not overlap the other bands. The acquisition of the data was generated by driving the cursor along the transect and recording the radience values of every other pixel (a software design constraint) while in the profiling mode.



NOTE: The large variation of relative radiance values of MSS Bands 4, 5, 6 and 7 are caused by the intensity of the northwest and southeast facing slopes. The Solar illumination is from the southeast. The spectral resolution is set at 128, 128, 128, and 64 for MSS bands 4, 5, 6, and 7.

Figure 3.—Spectral response profile across transect B from points B₁ to B₂.



Scale 1:62 500

Figure 4.— Transect B orientation to local terrain.

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Essentially, the data thus acquired should correspond with the ridges and valleys along the transect, that is, each dip in radiance values should correspond to a transition from a southeast face to a northwest facing slope and, conversely, each rise in value should indicate a transition from a northwest face to a southeast facing slope. To verify this observation, the radiance values were then correlated with the topography as shown on the USGS maps. Figure 3 dramatically illustrates the large fluctuations of the radiance values with the terrain slopes and the changing forest reflectance along Transect B.

The results of this preliminary step, besides demonstrating the above correlation, revealed that the inclination of the majority of the slopes was not great enough to produce a true shadow and that the observed phenomenon was indeed caused by a combination of terrain slope, Sun elevation, and bidirectional reflectance of surface features. To demonstrate how this phenomenon could affect a spectral classification, an unsupervised classification was made of the area containing Transect B. The classification consisted of eight nonoverlapping classes with the spectral bounds for each class selected at the option of the computer software. The results are shown in figure 5. The classes symbolized by : and " represent the northwest facing slope while the southeast slopes are represented by the symbols &, #, %, and \$. Grasses and water were indicated by (and ', respectively. The outlined areas in figure 5 represent the pseudoshadows caused by the Sun's low grazing angle. From this classification it is apparent that approximately 35 percent of the trace of the transect is affected by the terrain characteristics and low Sun angle.

Based on the results of the above classification and a need to acquire more precise data, a series of slopes containing a near uniform canopy of mixed hardwood was selected along the trace of Transect B for mensuration of the radiance values. The Image 100 system was used again to acquire the data while employing the

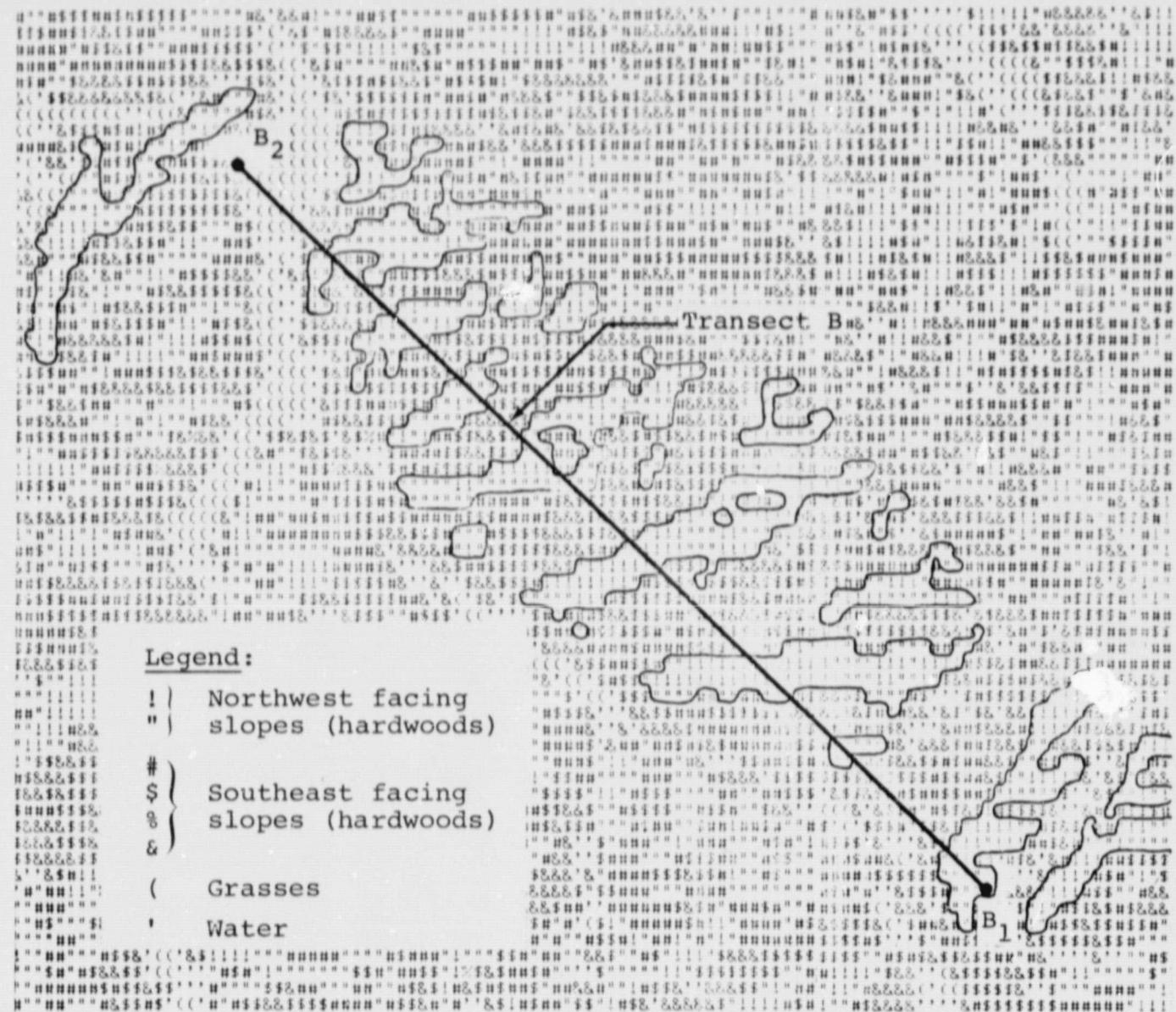


Figure 5.— An unsupervised classification utilizing eight spectral classes in the area of transect B.

cursor in a target acquisition mode in order to insure optimum positioning of the cursor. Due to the size of the cursor (2 by 2 pixels) the apparent shadows had to be large enough to accommodate the cursor so that it could be positioned totally within the targeted area.

Figure 6 illustrates the spectral response from the selected targets representing the northwest and southeast slopes. As indicated by the response in Landsat bands 6 and 7, there is sufficient separation to form at least two major spectral groups or classes based on the slope and aspect angle. Of major significance is the wide variance in radiance within the two groups. This is especially pronounced in band 7 and to a much lesser extent in bands 5 and 6, while band 4 is the least affected. These variances are not necessarily attributed to only the terrain, slope and aspect, and Sun angle, but may be attributed to a certain amount of inconsistencies within the vegetation cover, such as stage of growth, tree height, density, and specie mix.

7. COMPUTATIONS

The second objective of this study focused on the development of a means for reducing the effects of terrain slope and Sun angle on Landsat radiance values. A simplified approach was desirable considering the time allocated for the task and the additional expense required of a more sophisticated effort which may or may not prove effective.

The model, herein discussed, reduces the variance in spectral response cause by the terrain slope and Sun angle. This was achieved by normalizing all measured slopes along the transect to an incident angle of zero degrees, thus reducing the variation caused by the slope. Figure 7 illustrates the pertinent illumination conditions. From this simplified geometry, it can be determined that the radiance (C), represented by the relative

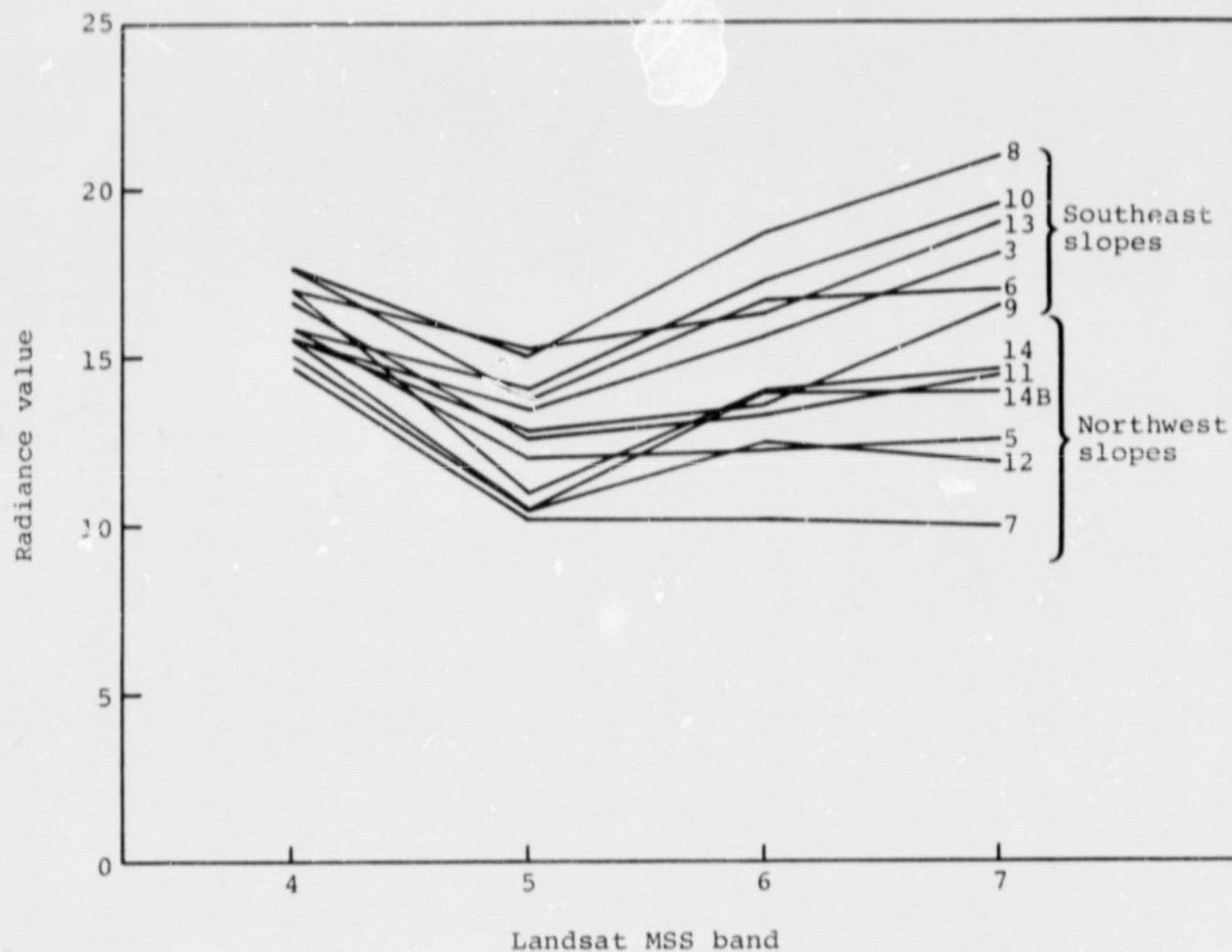
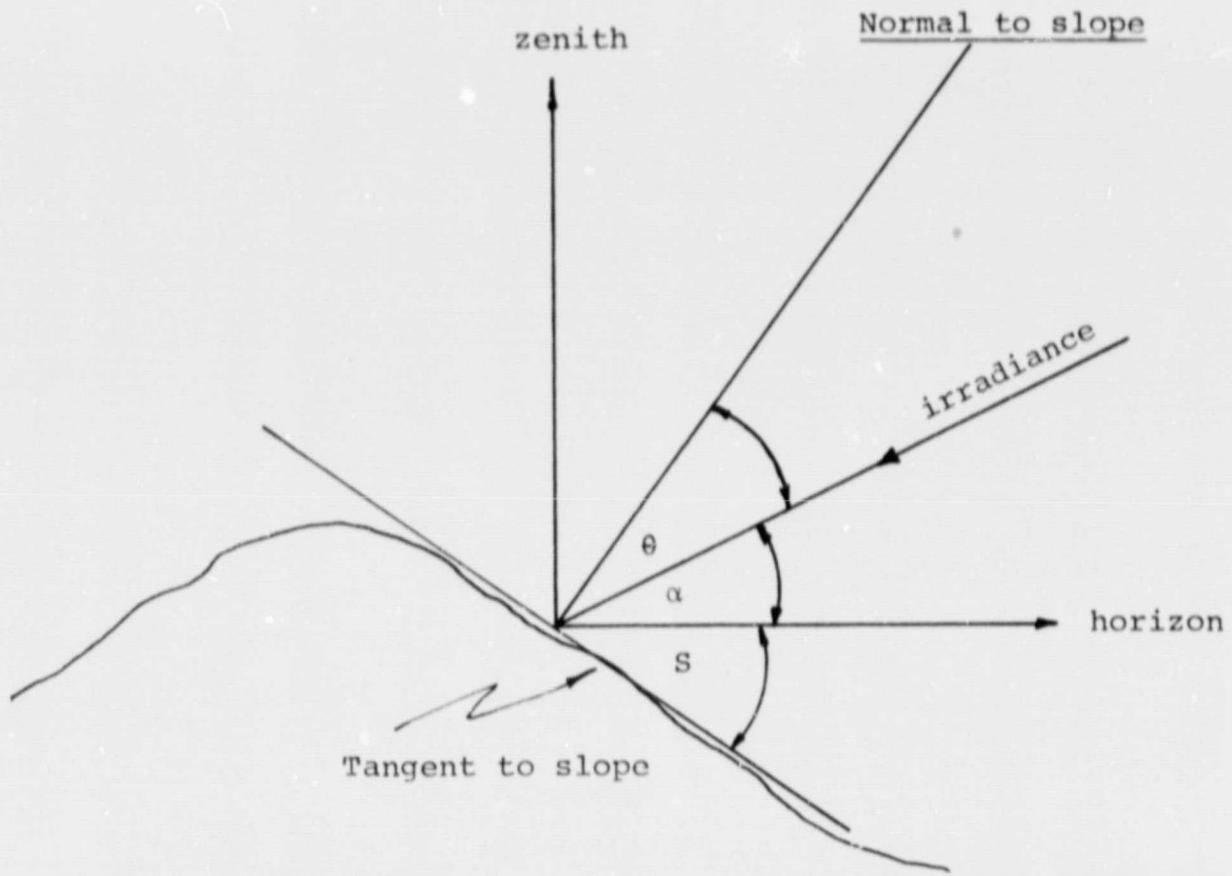


Figure 6.—Landsat spectral signatures representing mixed oak class and showing signature variation due to aspect angle.



S = slope angle

θ = sun's angle of incidence

α = elevation angle of sun

$\theta = 90^\circ - \alpha - S$

Figure 7.- Illustration of simplified radiation geometry.

radiance counts for each pixel is

$$C = k \cos \theta + n$$

where k and n are constants and θ can be determined from the known values of Sun elevation (α) and terrain slope (s) by

$$\theta = 90^\circ - \alpha - s$$

where the southeast slopes are positive in sign and the north-west slopes negative.

This procedure assumes that all radiance values are a linear function of cosine theta and that small inconsistencies may be attributed to inaccuracies in mensuration and/or the spectral inconsistencies of like vegetation. These small variations can be reduced to a minimum by linear regression and the constants k and n estimated (see appendix A).

Utilizing the constants k and n , as derived for the linear regression of Landsat band 7 and an estimated cosine θ , a set of corrected radiance values can be calculated which is independent of slope from the following relationship:

$$C_{ij}^* = C_{ij} + k_i (1 - \cos \theta_i)$$

where i and j refer to the sensor bands and pixels, respectively. For the complete derivation of the above formulae refer to appendix B.

Table 2 represents the preprocessing of the Landsat data by an empirical transformation having the form of the above equation and where the constants k and n (appendix A) were derived from a linear regression based on related spectral values and terrain slopes.

TABLE 1. - MSS REFLECTANCE IN RADIANCE VALUES SHOWING UNCORRECTED VERSUS CORRECTED DATA AND RESULTANT STANDARD DEVIATIONS FOR EACH LANDSAT MSS BAND.

θ = Incident Angle of Sun

\bar{X} = Arithmetic Mean

8. DISCUSSION

The classification of forest types, as compared to croplands, is by no means a simple process, especially since forests are indigenous to hilly and mountainous terrain where the slopes and aspect angle may cause phenological changes to the vegetation. This effect of steep terrain is compounded in the winter months when the Sun is low on the horizon. The resulting low light-level, coupled with sloping terrain has a tendency to increase the relative contrast between the illuminated slope and the opposite slope to the obvious detriment of the classification. In an attempt to solve this problem, initial thoughts may consider a simple clustering algorithm where one cluster may define the illuminated slope and the other cluster the opposite slope. However, all slopes exist, not just two, as there is a continuum of values.

In the method presented here, an attempt is made to increase the accuracy of classifying forest areas by reducing the variation in spectral response due to terrain slope and Sun angle. In other words, by reducing the original Landsat signatures to a surface normal to the Sun's elevation, the large variation between the Sun-lit slope and the opposite slope to the Sun would be minimized. This effect is diagrammatically illustrated in figure 8, where the mean values of the corrected data for Transect B were plotted in addition to the minimum/maximum radiance values of the targets. The reduction in variance can easily be seen when compared to the uncorrected data in figure 9.

It should be noted that the data for band 7 were used to calculate the new estimated cosine of theta; hence, all previous values have been reduced to one common value of a zero variance. Band

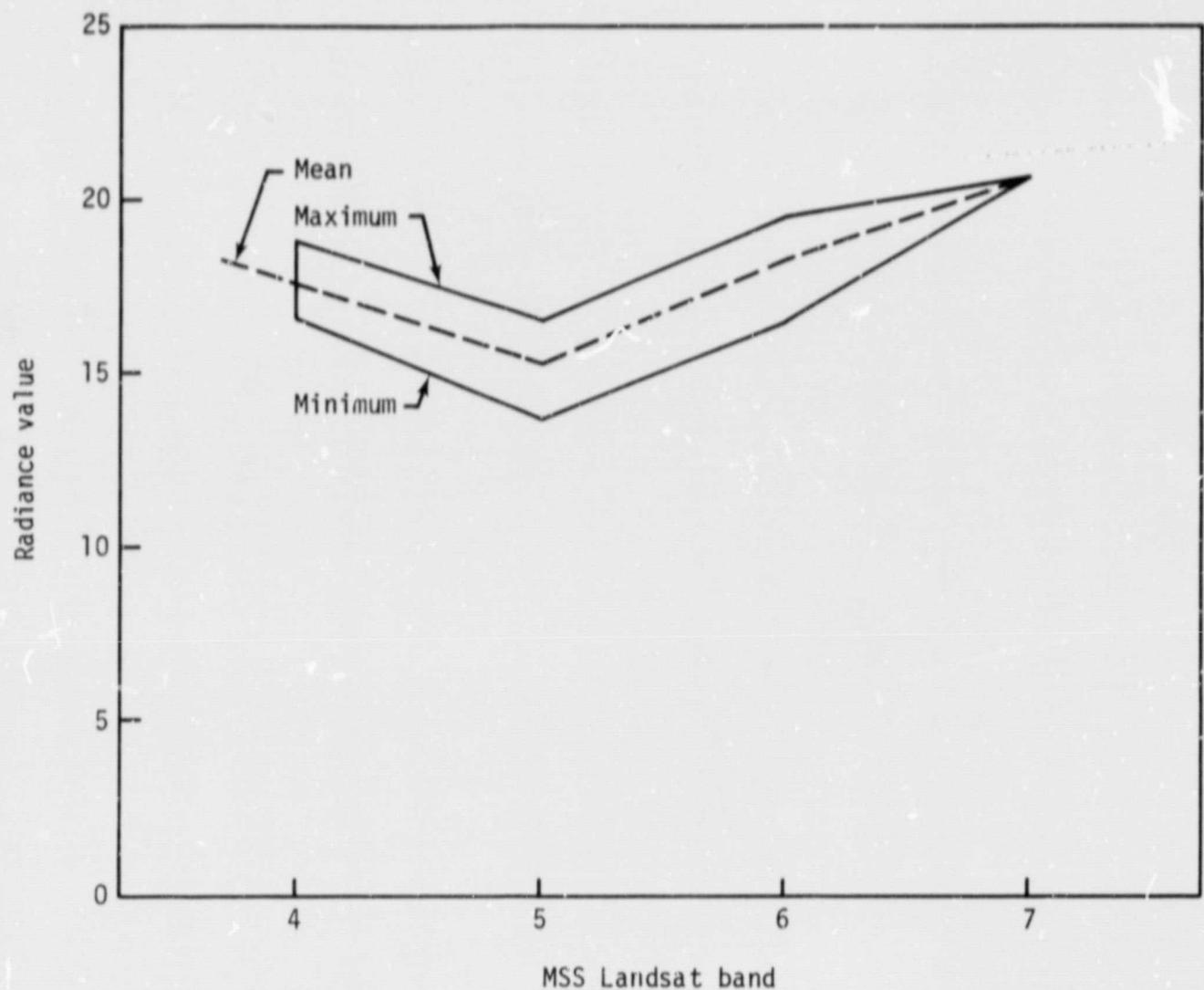


Figure 8.— Mean corrected signature showing reduced variation in spectral response.

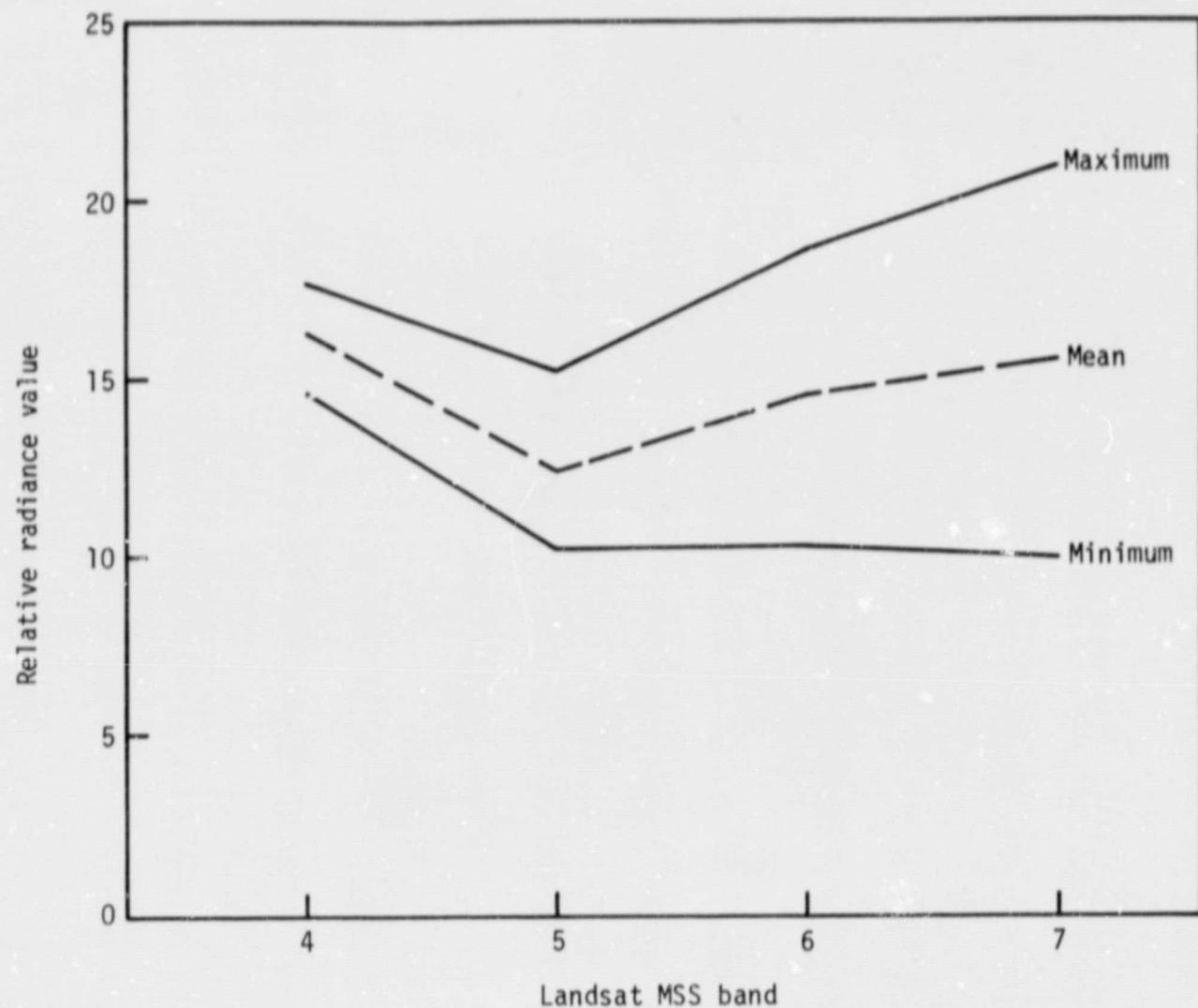


Figure 9.— Uncorrected mean signatures and the minimum/maximum variation for each band.

7 was selected to derive the values for theta because of the sensitive response to the angle of slope and the fact that it is least affected by haze.

9. CONCLUSIONS AND RECOMMENDATIONS

The work which has been accomplished thus far indicates that the model has definite promise. During the study several approximations were deliberately made in order to provide a quick assessment as to the potential of the method. The authors are in full agreement that the method could no doubt be improved by considering all significant factors. However, this experiment provided preliminary indications of success by reducing signature variance which in effect is a contributory cause of misclassification. Additional data and testing are required to confirm the applicability of this method under various conditions. Based upon the foregoing study concerning the effects of terrain slope and low Sun angle on forest albedo, the following tentative conclusions can be made:

- The Landsat spectral response varies considerably in areas of steep slopes and low Sun angles
- The large variation of spectral response influences discrimination accuracies to the detriment of the overall classification
- The spectral variation can be reduced by employing a simplistic illumination model to minimize the influence of topographic slope and low Sun angle

It is recommended that future work should be organized as follows:

- a. Phase 1 - The plans for the immediate future should center on completing the remaining six transects so that the variable factors of vegetation types, aspect, and slope can be correlated to the mensurated radiance values.

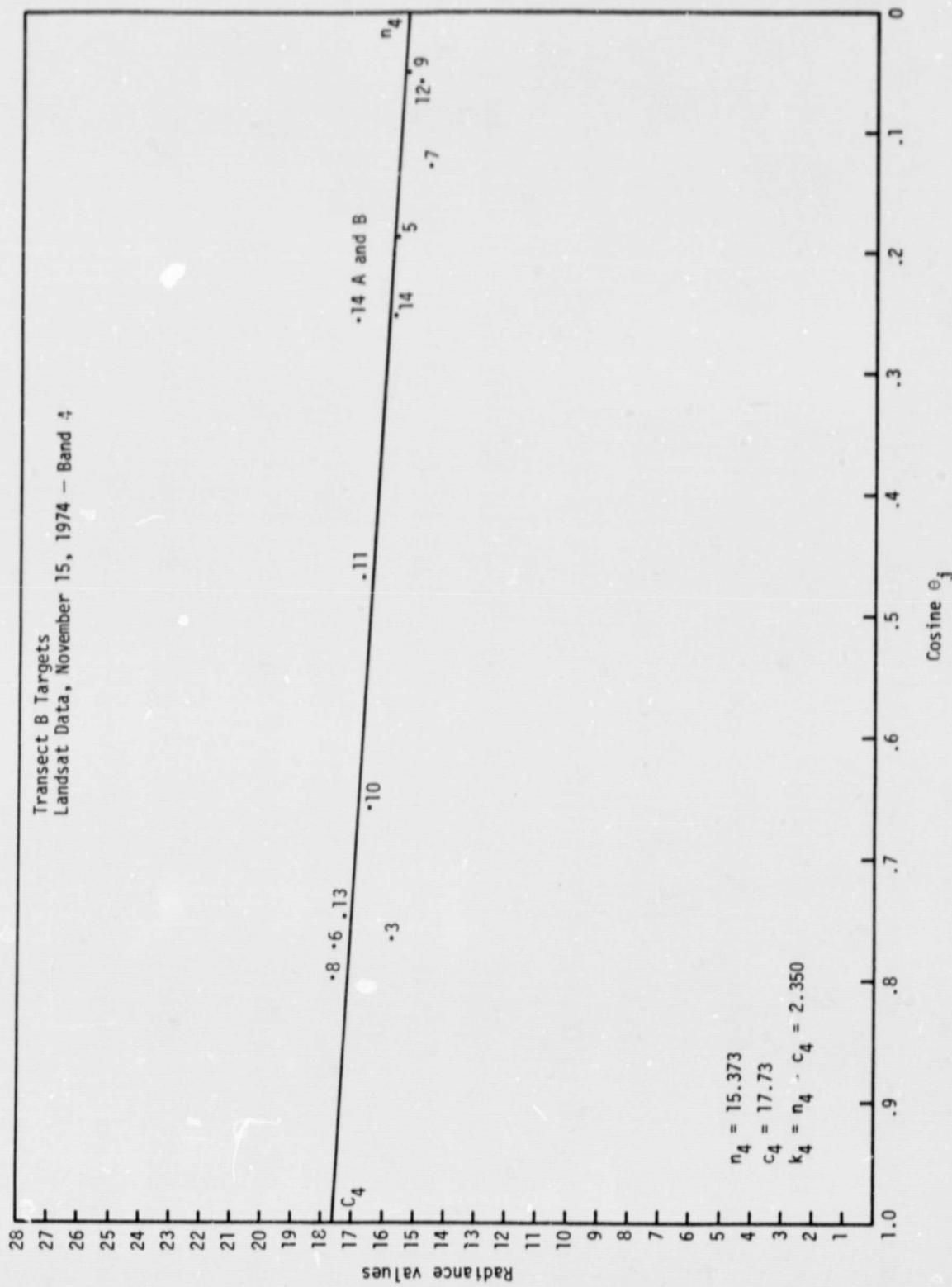
This phase will also contribute to the development of improved techniques for mensuration of radiance values and determination of terrain slope and aspect angle.

- b. Phase 2 - This phase will utilize the data and expertise acquired in Phase 1 to develop a cost effective working model applicable to forest inventory needs. It is recommended that Washington County, Missouri, be designated as the initial test site due to availability of both imagery and ground data for analysis and assessment of the working model.

10. REFERENCES

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3. Ciccone, R. C., Malila, W. A., and Crist, E.P.: Investigations of Techniques for Inventorying Forested Regions, Volume II: Forestry Information System Requirements and Joint Use of Remotely Sensed and Ancillary Data. NASA CR (Unknown) ERIM 122700-35-F2, Environmental Research Institute of Michigan, Ann Arbor, Michigan, November 1977.

APPENDIX A
TRANSECT B TARGET GRAPHS



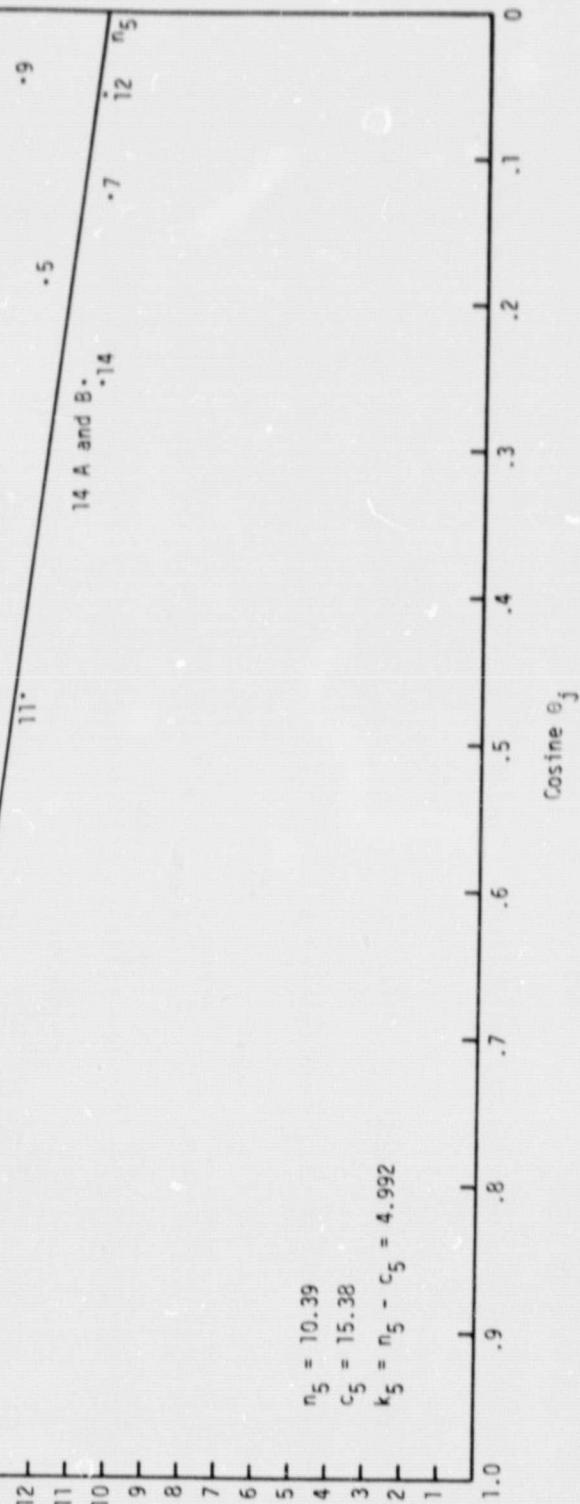
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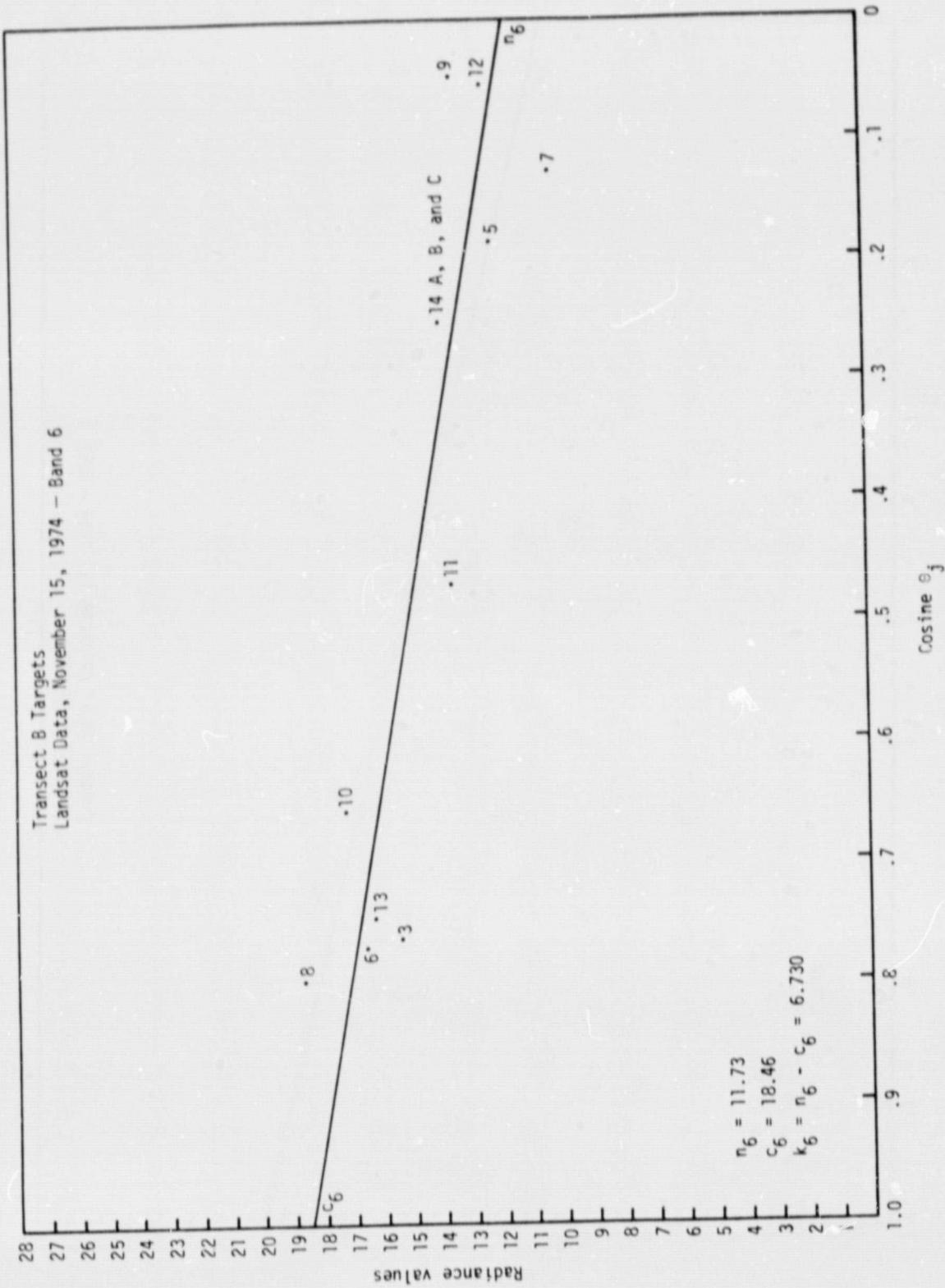
Transect B Targets
Landsat Data, November 15, 1974 - Band 5

Radiance Values

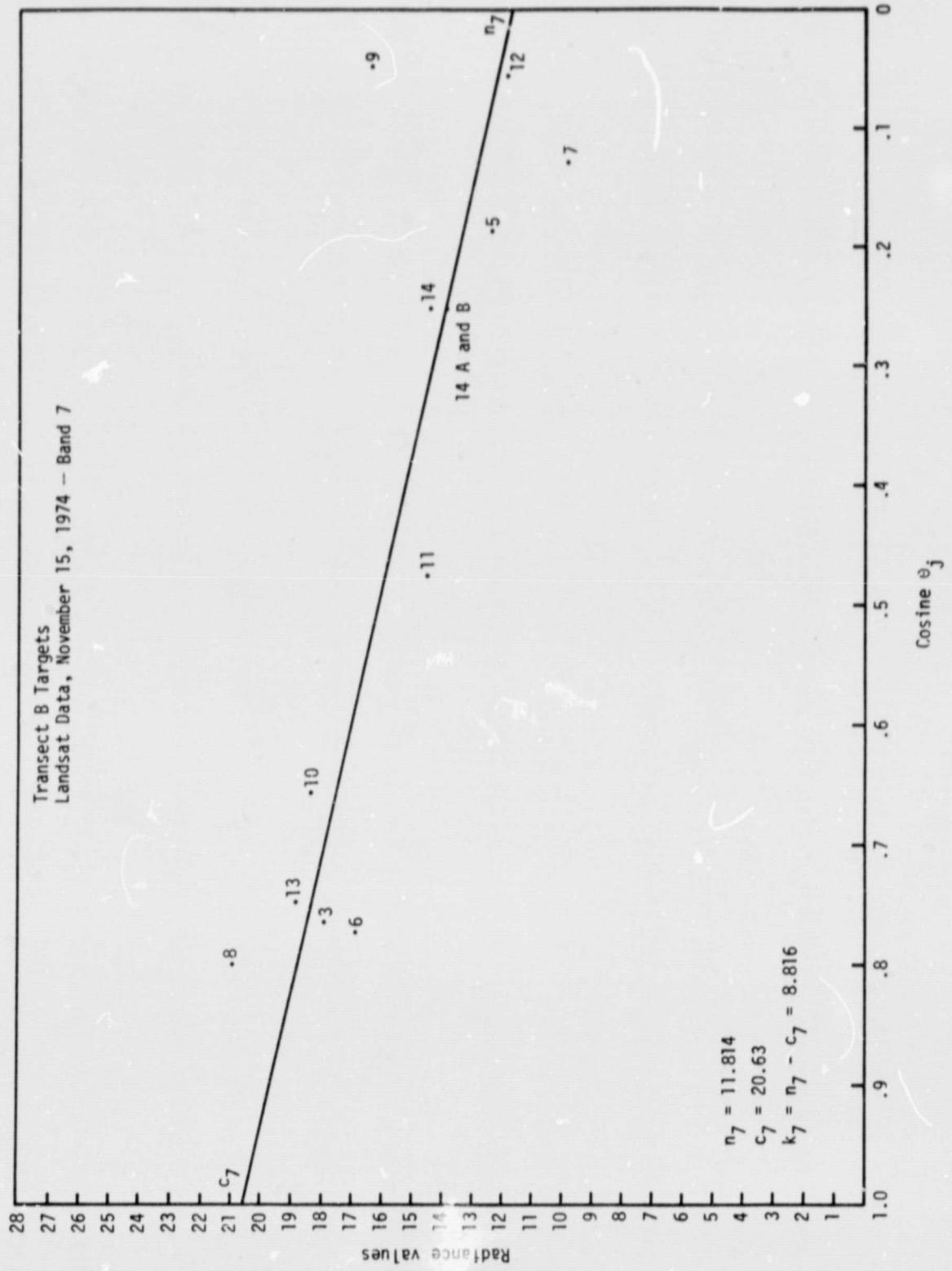
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Transect B Targets
Landsat Data, November 15, 1974 - Band 6



A-3
25



$$\begin{aligned}n_7 &= 11.814 \\c_7 &= 20.63 \\k_7 &= n_7 - c_7 = 8.816\end{aligned}$$

APPENDIX B

A METHOD OF REDUCING CLASSIFICATION
ERROR DUE TO SLOPE AND LOW SUN ANGLE

APPENDIX B

A METHOD OF REDUCING CLASSIFICATION ERROR DUE TO SLOPE AND LOW SUN ANGLE

The physical quantity that corresponds to the pixel radiance of a given band of Landsat data is the radiant power detected by the sensor. From theoretical considerations the pixel radiance C is linearly proportional to the cosine of the angle of incidence (θ) of the Sun onto the area represented by the pixel. A simple formula for the radiance of a pixel area is

$$C = k \cos \theta + n \quad (1)$$

where k and n are constants. For the i th sensor band and the j th pixel

$$C_{ij} = k_i \cos \theta_j + n_i \quad (2)$$

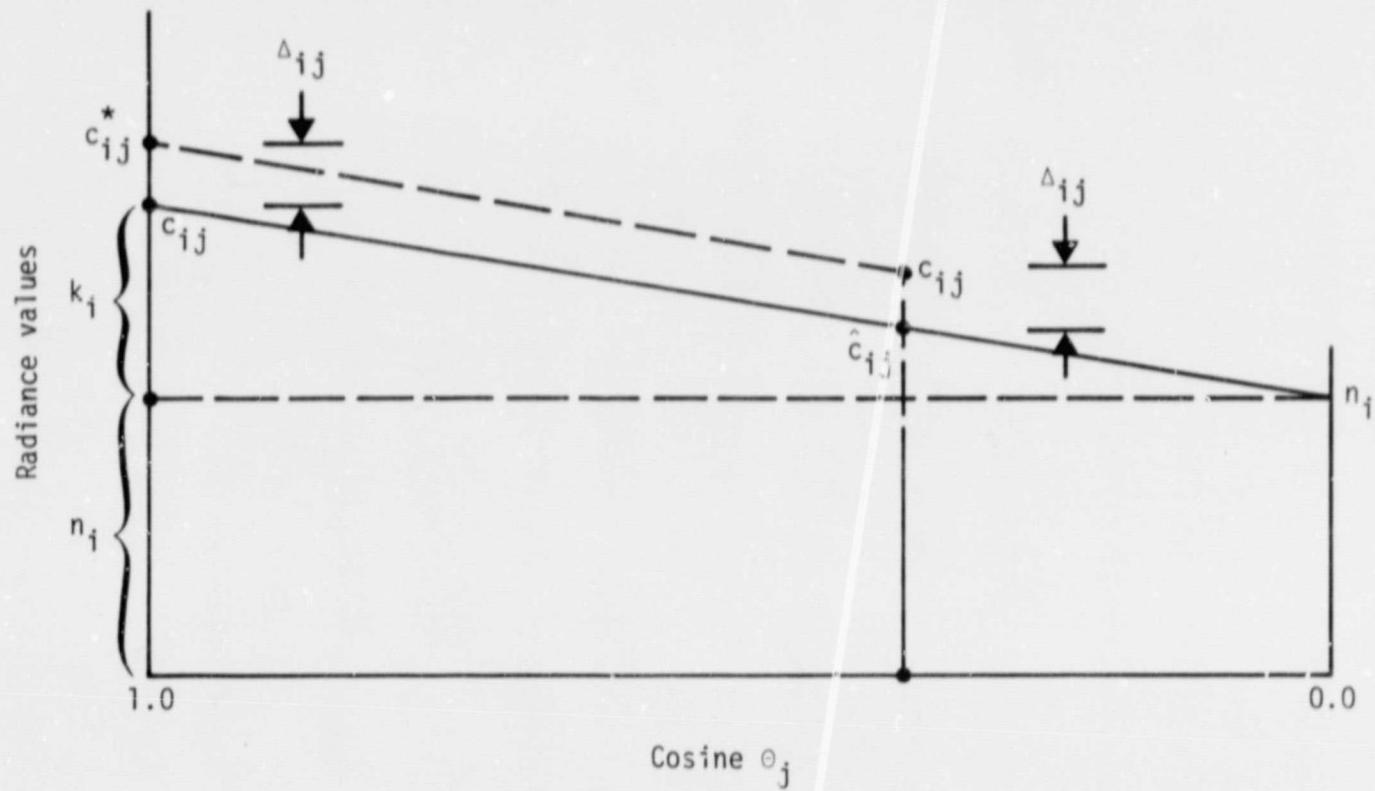
By employing the linear statistical model with error term Δ_{ij} , i.e.,

$$C_{ij} = k_i \cos \theta_j + n_i + \Delta_{ij} \quad (3)$$

and an adequate sample of pixel measurements C_{ij} and θ_j (θ_j is deduced from slope and aspect measurements), the constraints k_i and n_i can be estimated by linear regression. This enables subsequent estimation of the regression line radiance values c_{ij} for any Sun angle θ_j , i.e.,

$$C_{ij} = k_i \cos \theta_j + n_i \quad (4)$$

Assuming that surface feature information is superimposed onto the θ dependent regression line, the basis for the radiance modification is to replace the pixel radiance value C_{ij} with the expected value at normal incidence ($\theta = 0^\circ$), plus the deviation Δ_{ij} at θ_j (see fig. B-1) to obtain:



\hat{c}_{ij} expected reflectance at slope θ_j based upon regression

c_{ij} measured reflectance at slope θ_j

c_{ij}^* reflectance at slope θ_j corrected to vertical Sun

k constant derived from regression intercepts

$k_i + n_i$ slope and intercept of regression line

Δ_{ij} deviation of measured radiance from expected radiance

i band index

j target (pixel index)

Figure B-1.- Line of regression for c_{ij} versus cosine θ_j .

$$c_{ij}^* = (k_i + n_i) + \Delta_{ij} \quad (5)$$

where c_{ij}^* is the modified pixel radiance and

$$\Delta_{ij} = c_{ij} - \hat{c}_{ij} \quad (6)$$

Substituting for Δ_{ij} in equation (4) gives

$$c_{ij}^* = c_{ij} + k_i (1 - \cos \theta_j) \quad (7)$$

In order to circumvent the necessity for computing each θ_j from slope and aspect measurements, $\cos \theta_j$ can be estimated from equation (4) using the radiance data from one of the bands (band 7 is chosen in this study). An estimate of $\cos \theta_j$ is given by

$$(\cos \theta_j) = (C_{7j} - n_7)/k_7 \quad (8)$$

Substitution into equation (6) given

$$c_{ij}^* = c_{ij} + k_i [1 - (\cos \theta_i)] \quad (9)$$

This procedure enables pixel radiance modification in three bands at the expense of one band. Three band classification can be performed on this modified data which is essentially independent of any slope effects other than true shadow.